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REPORT ON THE THIRD UNITED NATIONS INTERNATIONAL TRAINING COURSE ON REMOTE-SENSING APPLICATIONS TO GEOLOGICAL SCIENCES, CO-SPONSORED BY THE CARL DUISBERG SOCIETY BERLIN AND THE EUROPEAN SPACE AGENCY IN COOPERATION WITH THE GOVERNMENT OF GERMANY

(Potsdam and Berlin, Germany, 7-25 October 1991)

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INTRODUCTION

A. Background and purpose of the course

1. The General Assembly, at its thirty-seventh session, adopted resolution 37/90 of 10 December 1982, endorsing the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) that the United Nations Programme on Space Applications should promote the growth of indigenous nuclei and an autonomous technological base in space technology at the local level. At its thirty-third session, in June 1990, the Committee on the Peaceful Uses of Outer Space endorsed the United Nations Programme on Space Applications for 1991 as recommended by the Scientific and Technical Subcommittee of the Committee at its twenty-eighth session. Subsequently, the General Assembly, at its forty-fifth session, endorsed the activities of the Programme on Space Applications for 1991 (resolution 45/72).

2. The third United Nations International Training Course on Remote-Sensing Applications to Geological Sciences was part of the 1991 activities of the United Nations Space Applications Programme. The training course was co-sponsored by the Carl Duisberg Society Berlin and the European Space Agency (ESA), organized in cooperation with the Government of Germany and hosted by the Central Institute for Physics of the Earth Potsdam and the Free University of Berlin, Germany, from 7 to 25 October 1991.

3. The objective of the training course was to provide education and practical training to participants from developing countries and Eastern European countries with respect to techniques, methods and results of recent applications of airborne and satellite remote sensing to geological sciences. The following topics were covered by the programme of the training course:

(a) Fundamentals of remote sensing including analog-optical and digital image processing, classification procedures, geostatistics, analysis of geological units, lineament analysis and field checking;

(b) Geological fieldwork in two units of the Central European Hercynides (Harz Mountains and the Vogtland block) in the eastern part of Germany, carried out in areas of different geological structures (basement, cover rocks) under humid climate;

(c) Practical work in data classification by means of aerial photographs and satellite images, controls of mapped remote-sensing features, training in data collection of spectral behaviour of rock and soil units and its interpretation;

(d) Interpretation and development of geological models.

4. The present report, which covers the background, objectives and organization of the training course, as well as a summary of presentations, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants in the training course will report to appropriate authorities of the Government, universities and research institutes in their respective countries.

5. Participants expressed their appreciation to the United Nations and to the Government of Germany for organizing and hosting the course, for their financial assistance and for the scientific and technical quality of the training course.

B. Organization of the course

6. Invitations to nominate participants for the International Training Course were sent by the United Nations to developing countries and Eastern European countries. The course was attended by 19 participants from the following countries: Bangladesh, China, Czechoslovakia, Ghana, Hungary, India, Jordan, Mongolia, Pakistan, Philippines, Poland, Romania, Sudan, Syrian Arab Republic, Thailand, Viet Nam, Yemen and Zimbabwe. The participants were scientific and technical personnel actively engaged in geology and remote sensing in their respective countries.

7. Instruction for practical work and lectures were provided by experts from Finland, Germany, Italy, the Netherlands, the Union of Soviet Socialist Republics and the European Space Agency.

8. The Carl Duisberg Society Berlin, the Central Institute for Physics of the Earth Potsdam and the Institute for Geology, Geophysics and Geoinformatics of the Free University of Berlin coordinated the local arrangements and provided the technical equipment, materials, course facilities and local transportation.

9. Funds allocated by the United Nations and the European Space Agency were used to cover the cost of international travel for 19 participants. The Government of Germany, through the Carl Duisberg Society, Berlin, provided fellowship to cover subsistence and course fees for those participants.

10. Welcoming addresses were presented by Mr. B. Schleich, on behalf of the Carl Duisberg Society Berlin, by Mr. W. Schunack, on behalf of the Free University of Berlin, by Mr. E. Hurtig, on behalf of the Central Institute for Physics of the Earth Potsdam, and by Mr. H. J. Haubold, on behalf of the United Nations.

11. The training course consisted of a series of integrated lectures, presentations of case studies, exercises and field trips to different geological areas in the eastern part of Germany. The proceedings of the training course will be published in the Berliner Geowissenschaftliche Abhandlungen of the Free University of Berlin, Germany.

SUMMARY OF THE COURSE

A. Introduction to remote-sensing interpretation for geological sciences

12. Satellite remote sensing is especially useful for applications to survey tasks which do not require too much direct ground information; in other cases, the use of airborne or ground-based observations provides more detailed information. Satellite remote sensing is well suited for geological reconnaissance surveys, especially in arid and semi-arid areas.

13. Satellite images contain integrated information on such features as vegetation, soil, rocks, land forms, drainage patterns and geologic structures. Thematic interpretation of these complex patterns of forms, shades, colours, structures, textures and their mutual relationships requires, besides some background about the physical fundamentals and peculiarities of remote-sensing data, a thorough understanding of the processes of relief formation and their dependence on climate, the relationships between relief, rock types and geological structures, between the interaction of endogenous and exogenous Earth-shaping forces, between the scale of features and their possibly more deep-seated origin and between soils and vegetation cover. In summary, it requires well-founded interpretation models besides an appropriate level of knowledge in geological mapping, computer processing and other techniques of data processing and presentation as well as the availability of independent data sources, e.g., ground control points.

14. There exists no unique complex interpretation model with which to extract from remote-sensing imagery the diverse information of interest to geologists. Analysis of soil type is very different from structural analysis. Thus image interpretation always requires image "filtering" by enhancing and/or undertaking a selective evaluation of image features based on spectral signatures relevant for the given survey tasks. So that it is first necessary to define the task properly and subsequently choose the most appropriate procedures and methods of data collection (including ground control), processing, evaluation and presentation.

15. The geological interpretation of remote-sensing data attempts to relate characteristics of the Earth's surface to sub-surface phenomena and causes. The crustal depth to which the surface interpretation might be extended downwards depends on the scale of features considered and on the method used.

16. Despite the mostly large scale of satellite remote-sensing imagery, its geological interpretation should not be restricted to a general survey but should strive to be as detailed as possible. This may be achieved by incorporating independent small-scale (large-resolution) information into the interpretation process, such as aerial photography or side-looking airborne radar (SLAR) images, available maps and ground verification. The results of thematic information extraction should be presented in as many different topical maps as possible (drainage, land forms, land use, soil types, vegetation, rock units, lithology, photolineations). Finally, the geologist

should try to determine the processes which could best explain the development of these various features and their interrelationships.

17. The endogenous forces that shape the Earth still persist; otherwise, the continents would be eroded to sea level within a time span of less than 15 million years. These processes lead, among others, to folding and faulting, to interaction with external forces of weathering and gravity and subsequently to erosion and redeposition. Planar and linear features related to these processes may be recognized on satellite images even if their intensity is very low. While ongoing internal geological processes normally result in broken symmetry and in homogeneity of features, erosion and redeposition tend to homogenize.

18. Many of the relief-forming processes of the continents are connected with lineaments. The latter are frequently related to scarps or other slope effects. These morphological features as well as differences in igneous or sedimentary rock types are recognized in remote-sensing imagery only indirectly owing to differential erosion, differences in soil porosity and water saturation, differences in tone or colour or those resulting from shadowing effects (especially in SLAR imagery). Reliable and quantifiable information about material composition can be derived only under favourable circumstances, which include the availability of high-resolution spectral data collection, appropriate processing and calibration by means of ground control data.

19. In most cases, it is not possible to identify the true nature of each individual feature seen or "suspected" by an interpreter in remote-sensing images or to find its location on the ground, especially since any visual interpretation process is not free of the influences of subjectivity, background knowledge and model concepts. Therefore, generalization and sometimes statistical evaluation of feature patterns derived from remote-sensing imagery are indispensable. Geological interpretation can go beyond the pure documentation of such features and should attempt to provide an understanding of the process. In this context, it should be noted that various rock types will react very differently when being subjected to the same type of crustal deformation. Granites, for example, will react with brittle fracturing while limestone would yield with folding.

20. Geological features that are recognizable in remote sensing not only permit inferences with regard to current status and past processes, but also allow the interpreter to draw, with different degrees of reliability, some conclusions with regard to future geologic events such as landslides or earthquakes.

B. Fundamentals of remote sensing

21. In its most general sense, remote sensing is the observation of a target (object) by means of a device (sensor) which is separated from the target by a given distance. Specifically, remote sensing of the Earth by satellites is the observation and measurement of the energy and polarization characteristics

of the emitted and reflected radiation of elements of the land, ocean areas and atmosphere of the Earth in different ranges of the electromagnetic spectrum. Information obtained through such a process can be used to describe the location, nature and time variation of natural parameters, phenomena and resources of the Earth's environment as well as of man-made objects and formations.

22. However, in order meaningfully to apply remote-sensing techniques, it is necessary for the user to be thoroughly familiar with the basic physical laws which govern the interaction of electromagnetic radiation with matter. These interactions, often referred to as the spectral properties of matter, are its reflectance, absorptance and transmittance.

23. In many remote-sensing applications, the use of various types of sensors, platforms and kinds of data collected at various altitudes (including also ground sampling) becomes essential since no single remote-sensing device or type of platform can provide the great variety of data required for complex and reliable interpretation.

24. Availability, continuity and timeliness of remote-sensing data as well as assured access to the data at a reasonable cost are among the factors that determine the benefits to be derived from remote sensing and its widespread incorporation into Earth information systems and decision-making processes. To date, such user-friendly and low-cost operational satellite systems which could provide such services or stimulate a sustained development in this direction are not yet in place.

C. Analog and digital image processing and photo-interpretation

25. The availability of multispectral aerial and satellite imagery has led to the development of new techniques for both image processing and photo-interpretation. While the human eye can differentiate only some 15 to 25 grey levels, it may distinguish thousands of shades of colours and hues. Multichannel projectors (with additive colour viewers) such as the MSP-4 multispectral projector allow the superposition of information contained in multispectral imagery in a way suitable for visual (analog) image interpretation. Such instruments also permit analog image processing and contrast enhancement such as the addition, subtraction and ratio of different spectral bands of the same image, which otherwise would require arithmetic operations by means of computers using digital remote-sensing data. However, digital image processing is more versatile, quantifiable and objective.

26. Image enhancement is the deliberate modification of an image in order to highlight selected spectral, radiometric and/or spatial features or areas on it. Multispectral classification is an information extraction process that analyses the spectral properties of data and then assigns each pixel to different classes on the basis of similar spectral signatures. This classification may be either supervised or unsupervised depending on whether the assignment to a class is based on spectral signatures determined for real

reference (calibrated) objects within the scene or whether it differentiates the scene only on the basis of predetermined spectral parameters (i.e., in the spectral domain only). More advanced classification techniques include those known as cluster analysis of the minimum-distance type, the maximum likelihood techniques and classification techniques using potential functions.

27. The availability of digital multispectral data from the LANDSAT programme accelerated the development and use of digital image processing in the mid-1970s. Computer-aided automatic or interactive image processing and analysis is becoming universal although its data products are still predominantly aimed at image enhancement and rectification, i.e., at providing optimal data presentations for visual interpretation. In addition, statistical analysis and classification of features as well as corrections made on the basis of multi-source data are more common. Image restoration processes recognize and compensate for data errors, noise and geometric distortion introduced by atmospheric effects, the scanning process, data transmission and reception.

28. Digital image processing of photographs requires the conversion of different image tones into different electrical signals that are subsequently digitalized. A broad variety of devices such as flat-bed scanners, drum scanners, laser-beam and television-scanning devices of different spatial and densitometric resolution is available today. Participants were introduced to instruments, both analog and digital, which could be used for image processing, viewing, map and image analysis.

29. Photo-interpretation of remote-sensing images is still the predominant use for such data in geology. In this very interactive interpretation process, the data are combined with information from other sources such as topographic and geologic maps, statistics and field data. An experienced photo-interpreter will identify features in the images chiefly by looking for differences or similarities in shape, size, pattern, structure, texture, topographic location, colour and tone. Their interpretation requires thorough knowledge of feature-context-cause relationships and of respective interpretation models.

D. Spectral response of surface objects in the visible, infrared and microwave range

30. In the visible, near and thermal infrared ranges of the electromagnetic spectrum, there are several pronounced absorption bands for iron as well as for various minerals (especially clay minerals) and rocks. High spectral resolution data in these spectral bands are therefore of promise in differentiating between various types of soils as well as between unaltered and altered (hydrothermally mineralized or weathered) rocks. However, the spectral resolutions required (about 1.5 nm) for detailed geochemical analysis or for mineral and rock discrimination (better than 40-100 nm) are not yet available on an operational and imaging basis.

31. Electromagnetic radiation observed in the visible and near infrared bands consists of reflected or back-scattered solar radiation, while thermal infrared energy, which is generally recorded in the two main atmospheric "windows" centred around 7 µm and 5 µm as well as in the 8-12.5 µm region, is emitted by the elements of the Earth's surface. The radiant emittance of an object depends upon its temperature and emissive properties. The emissivity of an object is the ratio between its real radiant emittance and that of a black body of the same temperature. The emissivity of magmatic rocks shows a minimum in the wavelength range between 8.5 µm and 11 µm with a shift to longer wavelength as the mineral content of the rocks becomes higher. Nevertheless, this potential for discrimination cannot yet be exploited to the limited spectral radiometric resolution of thermal infrared sensors owing to the fact that the emitted energy in this spectral range varies strongly with temperature.

32. Surface temperature is a carrier of geological information. However, it is influenced by many factors related to the sun, wind speed, air temperature, surface roughness, surface colour, humidity and plant cover. Geological information from the deeper crust is brought to the surface by geothermal heat flux. While daytime temperature measurements of the Earth's surface are rather noisy, with only a relatively small signal of geological relevance, repetitive observations during the night yield information about differences in thermal inertia of the material of the upper soil/rock layer. The thermal inertia of an object depends upon its moisture content, porosity and density. Analysis based on this property has been used successfully only on an experimental basis. Thus, the analysis of thermal infrared images is often combined with the use of images in the visible range.

33. The application of thermal infrared sensing in geology is especially promising in the following areas: (a) localization and monitoring of thermal anomalies connected with volcanic and geothermal activity and exploration of geothermal energy; (b) localization of temperature anomalies in connection with uranium and sulphuric ore exploration; (c) lithological mapping; (d) regional structural mapping; and (e) geological and geophysical engineering investigations.

34. While clouds and fog are practically opaque to electromagnetic waves in the visible and infrared range, they are transparent to microwaves in the centimetre and decimetre ranges. The microwave emissivity, reflectivity and penetration depth (skin-depth) properties of an object are mainly determined by its complex dielectric constant and thus by its electric conductivity. Since small amounts of water in soils and rocks change their electric conductivity drastically, the quantitative estimate of moisture content in soils and vegetation cover is one of the most attractive applications of passive microwave remote sensing. The apparent radiometric temperature and the reflectivity of objects observed in the microwave range depend, additionally, on the type(s) of material within the skin-depth and on the wavelength, polarization and angle of observation of the microwave radiation. To date no theory which takes all these parameters into consideration has been developed. Comprehensive collection of ground control is thus indispensable

for the proper interpretation of both passive and active microwave (imaging radar) data.

35. The strong influence of the texture of objects on the back-scattered radar energy can be of great help in identifying soil and rock types and vegetation cover, but this effect can be fully exploited only when measurements at different frequencies are available. This is not yet the case in most operational systems. A field experiment carried out by the Jet Propulsion Laboratory (United States of America), in Death Valley, where a great diversity of scales in surface roughness exists (salt deposits, sand, gravel, dunes, badlands, erosion features), has clearly demonstrated the potential of radar for separating various classes of objects according to their differences in surface roughness. A comparison between theoretical predictions and observed differences in radar brightness for these various classes showed good agreement in more than 70 per cent of the cases. Thus, surface elements which were not discernible on the basis of their colour and brightness in visible and near infrared images could be clearly differentiated on the basis of radar data.

36. One main advantage of radar imagery for applications in geology is its low viewing angle (especially in the case of SLAR). Even subtle geomorphologic-structural features are strongly emphasized as a result of radar shadows. Another benefit is the elimination of the screening effect of vegetation, which in conventional black-and-white photography masks details in rocks at the surface and in the topography. Radar imagery also enhances the photographic contrast between unconsolidated geologic units and bedrock. Alluvium, lacustrine deposits, landslide debris and similar units appear dark in tone and contrast sharply with more consolidated units. Different kinds of bedrock units, however, are indistinguishable on the radar imagery except where such units engender a characteristic form of topographic expression.

37. Radar imagery is particularly suitable for the detection of faults and other linear geomorphological features. They are most clearly visible when being illuminated by the radar beam perpendicular to their strike. Although radar shadowing causes some loss of information, about 70 per cent of linear features may be discernible in a one-side-look image, as compared to about 90 per cent in the case of a dual-look image. A combination of radar and multispectral satellite imagery has the additional advantage of compensating for the loss of information in the radar shadows and of combining the benefits of multispectral and detailed relief information.

E. Interpretation of satellite images for geological purposes

38. One of the key elements in geological interpretation of remote-sensing imagery is the identification, characterization and classification of photo-lineations. They may be related to ground features of different origin and surface expression such as linear depressions, fractures or joint zones, boundaries of soil types, lithological borders and bedding trends. Classifications of photo-lineations should take into account the area under

investigation, their length, direction, frequency and density, their morphology (negative, positive, drainage-related), structural type (simple, complex) and their detailed internal structure and contrasts in tone.

39. Lineaments are more frequent in areas of outcropping basement rocks than in those with platform covers. Drainage patterns indicate fault systems, watershed positions, morphology and differences in rock type and permeability. Although the main genetic types of faults (dip-slip, transcurrent and upthrust faults) tend to show some systematic differences in general surface appearance, their discrimination in satellite imagery is not yet satisfactory. Only 5-10 per cent of the lineaments identified in such imagery can be generically classified, with the proper identification of thrust faults being the most difficult. One obtains a higher percentage of accurate identification of fault types when working with aircraft images.

40. The interpretation of satellite images for geological problems may be approached in a variety of ways. One of these is to obtain more complete information about an object of interest by a combined analysis of many different types of images and independent contextual information. Another possibility is to learn more about the connection between superficial image features and deep-seated structures and causes. Neo-tectonic block movements often result in a higher frequency of photo-lineations. The distance relationships between them yield information on their depth extension, vertical "amplitude" and horizontal scale. They are positively correlated, thus allowing image interpretation at various levels. A third approach is to decipher the historical development of a section of the Earth from recent manifestations of patterns of image features and their mutual relationships. The offsetting or cross-cutting of older fractures, dykes, folds or rock units by younger ones is a typical example which allows the inference of relative age differences. Finally, information about geochemistry and/or mineralogy can be extracted within the limitations discussed in paragraphs 30 and 31 above.

F. Role of remote sensing in assessing geological hazards

41. One of the main applications of geological interpretation of remote-sensing imagery and other data derived from space techniques (e.g., on recent crustal movements) is to study recent and ongoing geological processes in order to assess geological hazards. The latter are diverse (such as earthquakes, landslides and volcanic eruptions) and are often intricately interrelated.

42. The first step in evaluating a geological hazard is to study the Neogene-Quaternary evolution of the territory of interest. Recent geological structures such as scarps, narrow depressions, linear zones of abundant watering or peculiar vegetation often appear more pronounced than ancient geological structures in satellite images. Areas of concentrated occurrence of recent crustal deformations are considered to be of potential seismic risk although not all recent structures, and faults in particular, have retained

their high activity. Thus it is important to determine the trend of neo-tectonic evolution of the region under study by determining whether movements in any specific place have accelerated or slowed down, and whether any restructuring has occurred. Space photography from the south-western Syrian Arab Republic revealed two major neo-tectonic elements of a northern and north-eastern trend. According to geological data of the Pliocene-Quarternary age, the former direction cuts across the latter and older direction (active until the Miocene period) in a right-lateral sense. Consequently the north-trend structures pose a greater seismic hazard.

43. In order to distinguish and map active faults, aerial and space images of different scales and types have to be evaluated. Images taken in the near infrared are especially useful for the analysis of fine relief features and are also very sensitive to variations in vegetation, which is sometimes even more indicative of Holocene activity of faults than changes in topography. SLAR images emphasize topography and help to make visible even subtle differences in elevation. In other areas, thermal infrared airborne images may be particularly useful in detecting soil moisture related to active fault zones. Lateral strike slipping of faults may be indicated by consistent curving or river valleys and gullies or by horizontal offsetting of alluvial fans with respect to their feeding valleys. Normal dip-slip or thrusting of faults are indicated, instead, by geomorphological scarps, variations in the depth of the fault-line cut in the terrain, the splitting of terraces and variations in their height. The recognition of these features requires high-resolution stereoscopic images.

44. Information derived through remote sensing can play only a complementary role in the required complex assessment of geological hazards. This information has to be evaluated together with the results of independent geological, geophysical, geochemical, geodetic and landscape observations, and repeated surveys are indispensable. This also applies to the monitoring of slow changes, such as creeping disasters, which are connected with the advance of erosion or sedimentation, desertification, salinization or to developing swamps due to alterations in the coastlines of seas and lakes and other geologically induced changes in the landscape.

G. Application of remote sensing for prospection of mineral deposits

45. The potential contributions of remote sensing to the exploration of both vein mineralization and strata-bound potash and salt deposits in the eastern parts of Germany were demonstrated by means of case studies conducted in the Harz Mountains and in the Vogtland. Emphasis was placed on identifying surface expressions of hydrothermal veins under conditions of humid climate and intense cultivation, i.e., of an anthropogenically heavily overprinted Earth's surface.

46. Vein mineralizations are bound to late Mesozoic uplifted blocks and genetically related to late Hercynian magmatism. In some cases they are also related to Permian volcanic activities as well as to a regional mobilization and circulation process generated by vertical block movements but without a clearly defined relation to magmatic activities. In case of the Vogtland mineralizations and their relationship to the regional water circulation regime (manifested in numerous mineral springs), a possible connection with local swarm earthquake activity was discussed in terms of natural liquid-induced seismicity.

47. Remote-sensing interpretations related to the exploration of mineral deposits in the eastern parts of Germany were based on Soviet Kate-200 and LANDSAT images, complemented by data from aerial photography (both high-flying aircraft and low-flying helicopter) and SLAR missions as well as ground-based field spectrometer measurements. These data, together with additional independent geoscientific results, were used to complement available knowledge about local and regional fault patterns and their mutual relationships, thereby yielding fresh insights into already known mineralizations, their genesis and their wider potential. The remote-sensing interpretations and inferences made by the participants were checked during field exercises in the training areas.

48. The major conclusions derived by the participants from these exercises were as follows: (a) the circulation of hydrothermal solutions is mainly controlled by the less mineralized principal faults; (b) the vein structures in the inner parts of block segments owe their mineralization to water circulation; (c) the photo-lineations identified in the remote-sensing data were dominated by morphological structures (mostly negative forms), water circulation (lower spectral reflectance), zones of hydrothermal alteration (higher spectral reflectance) and offsets of morphological magmatic veins and quartz zones sticking parallel to the fluorine spar vein structures; (d) the relative temporal succession of the tectonic elements could be determined by the criteria of cross-cutting faults; (e) the best results were achieved where remote-sensing data could be complemented by independent, detailed data from geophysical and pedo-geochemical mapping and by other geoscientific primary data; and (f) the combined analysis of various data sources maximizes information output, minimizes prospecting costs and leads to optimal selection of areas for detailed studies.

H. Remote-sensing applications in hydrogeology and water resources surveys

49. The use of remote sensing in hydrogeology is complicated by the fact that groundwater is not visible in the images. Thus, indirect inferences have to be drawn from surface features. Hydrogeological applications are further impeded by humid climate, dense vegetation cover and anthropogenic features.

50. During the past few decades, new remote-sensing techniques such as multispectral imaging in the visible spectrum, in the near and far infrared range as well as in the microwave range (radar) have made it possible to solve successfully many hydrogeological problems. Satellite airborne imagery is interpreted to show the prevailing rock types and potential aquifers. Drainage patterns provide information on the permeability of aquifers; repeated observation is indispensable in regions where drainage patterns change seasonally. In hydrogeological applications, geo-botanical information can be very useful. Particularly in semi-arid regions, the density of vegetation cover often reflects the amount of moisture in the weathered zone as well as the quality of water; it also provides insights into the tectonic features. As compared to conventional ground-based hydrogeological mapping, the survey time and cost for comparable map scales can be reduced by about 20-50 per cent by incorporating remote-sensing data.

51. In densely vegetated areas, relative changes in the groundwater level may be estimated from the leaf reflectivity and height of the canopy of the plant species considered. Groundwater pollution (e.g., by oil substances, heavy metals, cyanides and nitrogen compounds) affects leaf and canopy reflectance, particularly in the near infrared spectral range; thus, the degree and spread of water pollution may be detected and monitored.

52. Through remote sensing in different spectral ranges it is possible to determine with varying degrees of accuracy, in less time and at a smaller cost, several parameters of the water budget, such as infiltration, run-off, evapo-transpiration, soil humidity (although only in the uppermost tens of centimetres of the soil profile) as well as the location and quantity of inflow of groundwater to surface flow. Because of the unique spectral signature of water, remote-sensing imagery in the visible or near infrared is also particularly well suited for mapping and inventory of surface water bodies (lakes, ponds and fluvial environments). Repetitive observation of watershed areas can also play an important role in predicting water run-off during flood regimes and annual water availability, and thus contribute to improved planning of water exploitation, river navigation, management of water storage and discharge of dams for hydroelectric power and irrigation schemes. Remote sensing is also a powerful tool for monitoring water temperature and quality (e.g., water transparency, amount of suspended material, chlorophyll) or pollutants. All these factors were extensively discussed on the basis of a case study in West Africa.

I. Application of remote sensing to the study of arid and semi-arid lands

53. As a result of inaccessibility or climatic conditions adverse to man, it is often difficult to obtain needed geological and other environmental or cartographic data from arid or semi-arid lands by conventional methods. Therefore, repetitive and synoptic remote-sensing data, mainly from satellites, are of greatest value for quick investigation of these regions, for preparing resource inventories, monitoring environmental changes such as

progressive desertification and salinization of soils, assessing the grazing capacity of sparsely vegetated pasture areas as well as for geologic-tectonic, geomorphological and soil mapping.

J. Application of mathematical methods in remote sensing

54. Presentations were dedicated to the evaluation of multivariate data. Starting from general considerations with regard to the existence, generation and use of multidimensional features in geosciences, algorithms for decision-making were presented and demonstrated through simple examples.

55. The concept of unsupervised versus supervised classification was presented and demonstrated for the case of digital image processing. Particular attention was paid to the practical application of these algorithms under real conditions. With this aim, a presentation was given on two procedures used at the Central Institute for Physics of the Earth Potsdam. These procedures allow the interactive optimization of classifiers, the computer-aided quality control of the classification results and the possibility to combine different algorithms.

56. Fractals may be more than a mathematical curiosity. They offer a compact method for describing objects and formations. Thus, they are first and foremost a language of n-dimensional geometry. Many structures in nature have an underlying geometric regularity, known as scale invariance or self-similarity. The repetitive pattern defines the fractal dimension of the structure. Remotely sensed pictures of the Earth's surface can be created, in principle, by random fractals using the midpoint-displacement method.

57. The technical interest of fractals comes from their suspected practical importance. As an example, petroleum-bearing rock which typically contains fluid-filled pores of many sizes might be effectively understood as a fractal object.

58. A great practical potential of fractal geometry is to use it to describe objects by means of certain fractal dialects which can significantly reduce the amount of data necessary to transmit or store an image. The time and cost of transmitting satellite images to the receiver stations on Earth can be reduced by transforming the images into codes using fractal algorithms. The application of fractal type mathematical methods in the analysis of remotely sensed images is a focus of intense study.

K. Remote sensing and comparative planetology

59. Space techniques provide a powerful way of studying the Earth as a planet. Although in most cases space techniques only allow measurements of surface phenomena by remote sensing, they do provide quantitative boundary conditions essential to the definition of the models. These include the knowledge of many diverse components such as the Earth gravity field, the

Earth deformations and mapping of geological structure, the ocean global circulation and the ocean-atmosphere coupling, and the atmosphere energy budget and radiative transfer. A global understanding of the various physical components and their interrelationships is a prerequisite to the understanding of the evolution of the Earth as a planet of the solar system. Of course, the same is true for all other planets of the solar system.

60. The direct exploration of the solar system with the possibility of in situ measurements of the other planets and their atmospheres and magnetospheres is providing additional information which is extremely valuable for the understanding of the history and evolution of the planet Earth. Access to the environment of other planets, coupled with in-depth studies of Earth phenomena and with theoretical models, is crucial to the understanding of the detailed balances which maintain the climate system of the Earth.

61. The technique of remote sensing has been applied to planets of the solar system in recent years. Spacecraft data show that one hemisphere of Mars is dominated by a moon-like surface with many eroded craters. The other hemisphere contains many younger, less cratered volcanic plains, canyons apparently formed from geological faults and several enormous volcanic mountains larger than any others known in the solar system. Mars is the only planet besides Earth known to have had a long-term dynamic hydrological cycle. Despite its cold, dry climate and extensive areas of cratered terrain left over from ancient times, Mars shows abundant evidence of the action of water and ice earlier in geological history.

62. Seen through a telescope the planet Venus appears as a nearly featureless disk covered with clouds. Photographs made by space vehicles parachuted onto Venus showed a relatively clear scene with scattered angular rocks at one site and eroded-looking, soil-sprinkled rocks at the other. Radar measures from Earth and space revealed impact craters distorted by the thick atmosphere, volcanoes shaped like pancakes, intricate networks of fractures and a mysterious lava channel that snakes several thousand kilometres across the planet. There is the hypothesis that large parts of Venus' surface were reworked during a huge volcanic episode 500 million years ago, similar to outbursts seen on Mars and the moon.

L. Field exercises in training areas

63. The lectures and classroom exercises were complemented by field exercises in different training areas (Vogtland region and Sub-Hercynian basin/Harz border fault). Their main aim was to verify the inferences drawn from the interpretation of various types of remote-sensing imagery made during the course and from spectral signature measurements obtained under humid climate conditions.

64. In the Vogtland training area the following questions were discussed and related features demonstrated: (a) representation and characteristic features of the granite massif of Vergen as it affected land use patterns and

morphological features seen in remote-sensing imagery; (b) geology of the characteristics of rocks; (c) thematic interpretation of fold structures and of hilly terrain caused by diabasic monadnocks; and (d) interpretation of data based on remote sensing, geomorphology, geology and seismology in order to reveal relationships between tectonics, deformation features and local earthquakes.

65. The field exercise in the Sub-Hercynian basin and the Harz Mountains aimed mainly to illustrate: (a) the detection of different rock types and faults along the northern border fault zone of the Harz Mountains; (b) ground verification of the spectral characteristics of rock types by means of field spectrometer measurements; (c) field checking of fault zones characterized as linear zones of increased moisture content; (d) pattern recognition as a tool for rock discrimination; and (e) demonstration of the kinematic aspects of block tectonics under the uplifting conditions of the Harz block.

Annex I

PROGRAMME OF THE COURSE

Date	Time	Subject	Speaker
Tuesday 8 October	10-11 a.m.	Opening ceremony	
		Welcome address on behalf of the United Nations	H. J. Haubold (United Nations)
		Welcome address on behalf of the Carl Duisberg Society	B. Schleich (Germany)
		Welcome address on behalf of the Free University of Berlin	W. Schunack (Germany)
		Welcome address on behalf of the Central Institute for Physics of the Earth	E. Hurtig (Germany)
	11 a.m.-12.30 p.m.	Geology and remote sensing	P. Bankwitz (Germany)
	2-4 p.m.	Remote sensing and digital image processing: current status and trends	F. K. List (Germany)
Wednesday 9 October	9.30 a.m.- 12.30 p.m.	Introduction to the physics of remote sensing	F. K. List (Germany)
	2-4.30 p.m.	Data acquisition: remote sensing systems - photography, scanners, microwave systems	F. K. List (Germany)
Thursday 10 October	9.30 a.m.- 12.30 p.m.	Visual interpretation and digital image processing	F. K. List (Germany)
	2-4.30 p.m.	Hands-on demonstration: digital image processing (exercises)	F. K. List Ch. Bauer W. Koch Ch. Munier R. Schoele (Germany)

Date	Time	Subject	Speaker
Friday 11 October	9.30 a.m.- 12.30 p.m.	Digital image processing: application to geology with introduction to fieldwork (exercises)	P. Bankwitz H. U. Wetzel E. Bankwitz J. Pilarski J. Fritz (Germany)
	2-4.30 p.m.	Hands-on demonstrations: image processing and geological information systems (exercises)	F. K. List Ch. Bauer Ch. Munier W. Koch R. Schoele M. Schultz (Germany)
Saturday 12 October		Excursion to Potsdam	
Sunday 13 October	9 a.m.-3 p.m.	Excursion to the Christian Memorials of Martin Luther in Wittenberg	
	3-6 p.m.	Transfer to fieldwork (Vogtland block)	
Monday 14 October	9 a.m.-4 p.m.	Fieldwork in the Vogtland area: practical exercises, mapping based on geological fieldwork, aerial photo and satellite interpretation for mineral exploration and seismological events	P. Bankwitz J. Pilarski H. Kaempf (Germany)
	7.30-9 p.m.	Seismic hazards and remote sensing	V. Trifonov (USSR)
Tuesday 15 October	9 a.m.-3 p.m.	Continuation of fieldwork in the Vogtland area	
	3-6 p.m.	Transfer to the Harz Mountains	

Date	Time	Subject	Speaker
Wednesday 16 October	9 a.m.-4 p.m.	Fieldwork in the Harz Mountains and its foreland: interpretation of main fault structures, texture pattern of crystalline basement and sedimentary cover rocks, spectral characteristics of soil and rocks, exercises with mobile spectrometers	
		Geological exercises	P. Bankwitz E. Bankwitz J. Pilarski J. Fritz (Germany)
		Spectrometer exercises	H. Loeper W. Herr (Germany)
Thursday 17 October	9 a.m.-4 p.m.	Continuation of fieldwork in the Harz Mountains	
	4-6 p.m.	Transfer to Potsdam	
Friday 18 October	9 a.m.-12.30 p.m.	Remote sensing applications for hydrogeological projects in developing countries	W. Kruck (Germany)
	2-5 p.m.	Interpretation of remote-sensing data and development of geological models	P. Bankwitz
Saturday 19 October		Excursion to Berlin	
Sunday 20 October	9 a.m.-11.30 a.m.	Remote sensing - comparative planetology (Mars-Earth-Venus)	H.-P. Joens (Germany)
Monday 21 October	9 a.m.-12.30 p.m.	Remote-sensing applications in tropical Africa (geology, environment, soil, vegetation, forest)	M. Punkari (Finland)
	2-5 p.m.	Application of remote sensing to the study of arid and semi-arid lands	T. Woldai (Netherlands)

Date	Time	Subject	Speaker
Tuesday 22 October	9 a.m.-12.30 p.m.	Case study of remote sensing-aided geological mapping in Egypt	F. K. List (Germany)
	2.30-5 p.m.	Remote-sensing applications in water; case studies in West Africa	M. Antoninetti (Italy)
Wednesday 23 October	9-11.30 a.m.	Trends in recent digital cartography; creation of geoscientific maps	B. Meissner U. Ripke J. M. Grunicke (Germany)
	1.30-3.30 p.m.	Geostatistics and mathematical modelling for geological analysis	J. Harff B. Lewerenz (Germany)
	3.30-5 p.m.	Remote sensing and geomorphological analysis for neotectonic interpretation; problems of fractal geometry in remote-sensing data	J. Pilarski (Germany)
Thursday 24 October	9-10.30 a.m.	Trends of remote sensing in application of the ESA programme	J. Lichtenegger (Italy)
	11 a.m.-1 p.m.	Final discussion	
	2-4 p.m.	Closing ceremony	P. Bankwitz Ch. Kamlage E. Hurtig F. K. List (Germany) H. J. Haubold (United Nations)

Annex II

LIST OF PAPERS PREPARED FOR THE TRAINING COURSE

1. Antoninetti, M., Remote sensing applications in water - case studies in West Africa, Milan, Italy.

2. Bankwitz, P., Geology and remote sensing, Potsdam, Germany.

3. Bankwitz, P., Interpretation of remote-sensing data and development of geological models, Potsdam, Germany.

4. Bankwitz, P., Wetzel, H.-U., Bankwitz, E., Pilarski, J., and Fritz, J., Introduction to fieldwork in remote sensing (Vogtland, Harz Mountains), Potsdam, Germany.

5. Harff, J., and Lewerence, B., Geostatistics and mathematical modelling for geological analysis, Potsdam, Germany.

6. Joens, H.-P., Remote sensing - comparative planetology (Mars-Earth-Venus), Clausthal-Zellerfeld, Germany.

7. Lichtenegger, J., Trends of remote sensing in application of the ESA programme, Frascati, Italy.

8. List, F. K., Remote sensing and digital image processing: current status and trends, Berlin, Germany.

9. Punkari, M., Remote sensing application in tropical Africa, Helsinki.

10. Trifonov, V. G., Seismic hazards and remote sensing, Moscow.

11. Woldai, T., Application of remote sensing to the study of arid and semi-arid lands, Enschede, Netherlands.

12. The Participation of the United Nations System in International Space Year, United Nations, New York.

13. Project Document: Centre for Space Science and Technology Education, SAP/90/001/002/003/004, United Nations, New York.